IS 7146-4 (1974): Methods of measurement on photosensitive devices, Part 4: Photomultipliers [LITD 4: Electron Tubes and Display Devices]

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(Reaffirmed 2003)

Indian Standard

METHODS OF MEASUREMENTS ON PHOTOSENSITIVE DEVICES

PART IV PHOTOMULTIPLIERS

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Indian Standard
METHODS OF MEASUREMENTS ON PHOTOSENSITIVE DEVICES
PART IV PHOTOMULTIPLIERS

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Indian Standard

METHODS OF MEASUREMENTS ON PHOTOSENSITIVE DEVICES

PART IV PHOTOMULTIPLIERS

0. FOREWORD

0.1 This Indian Standard (Part IV) was adopted by the Indian Standards Institution on 11 December 1974, after the draft finalized by the Electron Tubes Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 In preparing this standard, assistance has been derived from IEC Pub 306-4 (1971) ' Measurement of photosensitive devices, Part 4 Methods of measurement for photomultipliers ', issued by the International Electrotechnical Commission.

0.3 This standard is one of a series of Indian Standards on photosensitive devices. A list of standards so far published in the series is given on page 20.

0.4 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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1. SCOPE

1.1 This standard (Part IV) deals with measuring methods for photomultipliers using discrete dynodes.

2. TERMINOLOGY

2.1 For the purpose of this standard, the terms and definitions covered in IS : 1885 (Part IV/Sec 8)-1973† shall apply.

3. MEASURING METHODS

3.0 General

3.0.1 All electrode voltage and temperatures shall be adjusted carefully to the stated values.

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*Rules for rounding off numerical values (*revised*).

†Electrotechnical vocabulary: Part IV Electron tubes, Section 8 Photosensitive devices

3.0.2 *Dimensions and Location of the Photosensitive Area* — The dimensions of the photocathode or the location and dimensions of the window in the envelope through which the cathode is illuminated shall be stated.

3.1 Cathode Luminous Sensitivity

3.1.1 For measuring cathode luminous sensitivity, a luminous flux in the range 10^{-5} lm to 10^{-2} lm from a standard lamp is commonly used.

3.1.2 The value of luminous flux used shall not be so large that resistance losses in the photocathode layer introduce measurement errors, or so small that leakage resistance currents make it difficult to measure accurately the current due to photo-emission from the photocathode.

3.1.3 The circuit employed for measuring cathode luminous sensitivity is shown in Fig. 1, where at least the first two dynodes shall be operated at normal voltages so that the electric field is not disturbed.

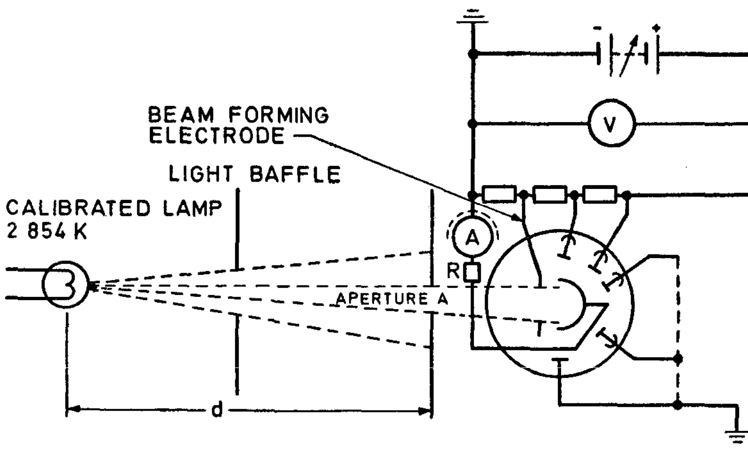


Fig. 1 System for Measuring Cathode Luminous Sensitivity

3.1.4 Where this effect is small, the tube may be connected as a diode, *R* is conventionally a resistance of approximately 1 MΩ whose function is to limit the current drawn if the tube being measured is defective (for example, gassy or short-circuited).

3.1.5 The current motor *A* measures the photo-emissive current.

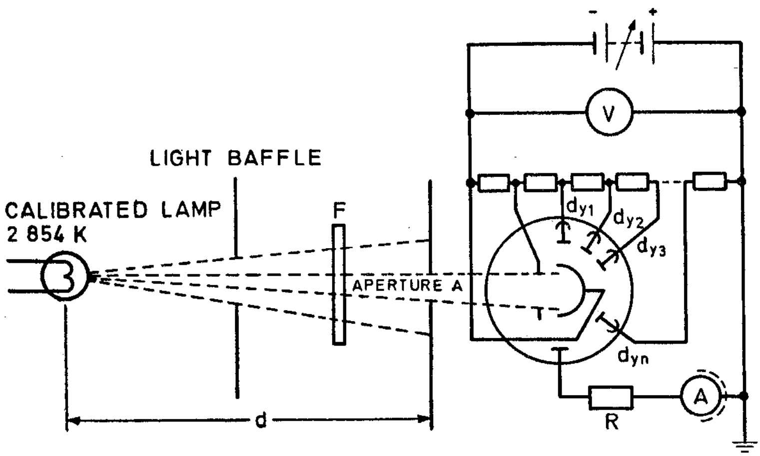
3.1.6 The measured currents being low, precautions shall be taken to avoid leakage current, for example, by connecting the shielding of the measuring instrument to ground and earthing the photocathode side. The voltage used shall be sufficient to ensure saturation, generally 100 to 400 V and saturation may be checked by increasing the voltage by 100 percent, which shall cause little increase in current.

3.1.7 In general, since the relation between luminous flux and current at low light levels is linear, a measurement at one value of incident luminous flux will be adequate.

3.1.8 Lack of saturation at higher flux levels may be an indication of resistive losses in the photocathode layer and will result in a departure from linearity.

3.2 Anode Luminous Sensitivity

3.2.1 For this measurement, the photomultiplier is connected as in Fig. 2, with a voltage source and a series of resistors in a voltage divider connected to each dynode and the anode. The anode current shall have a value below the maximum value specified by the manufacturer.



F = Neutral-density filter or other attenuator.

FIG. 2 SYSTEM FOR MEASURING ANODE LUMINOUS SENSITIVITY

3.2.2 For measurements of luminous sensitivity of a photomultiplier, a luminous flux in the range of 10^{-10} lm to 10^{-6} lm is commonly used. It may be necessary to use neutral-density filters to reduce the flux to these low values. A filter with a uniform transmittance throughout the visible and near infra-red regions is most desirable.

3.2.3 Since filter transmittance is generally not adequately uniform throughout this range, separate filter calibration is needed for tubes differing widely in their spectral sensitivity characteristics.

3.2.4 It is also possible to reduce the intensity by increasing the distance between the lamp and the photomultiplier or by using a lamp with lower intensity and the same spectral distribution.

3.2.5 Another means of reducing light level fairly equally at visible wavelengths is to insert a calibrated colourless diffusing screen between the source and the aperture in the systems illustrated by Fig. 1 and 2. This screen is preferably a glass plate thoroughly grit-blasted on both sides, but may also be an opal glass.

3.2.6 A further means of reducing the light level fairly equally over the near ultra-violet, visible and near infra-red portions of the spectrum is to use convex front-surface evaporated aluminium mirrors or diffuse reflecting surfaces, for example, screens of magnesium oxide or barium sulphate.

3.2.7 Response at several known flux levels shall be measured to confirm linearity.

3.2.8 When the gain of the photomultiplier is independent of the wavelength of the light incident upon the photocathode, and the collection efficiency of the first dynode is independent of this wavelength, the anode luminous sensitivity s_a can be obtaind from the cathode sensitivity s_k and the gain G:

$$s_a \longrightarrow = G \longrightarrow s_k \quad \text{(A/lm)}$$

s_k being known, it is then sufficient to measure G for a practically monochromatic radiation.

3.2.9 Anode luminous sensitivity measurements are usually taken at several values of applied voltage.

3.2.10 *Precaution* — Because most photomultipliers have nine or more stages, and because electron multiplication is a function of the voltage across each stage, the output current is approximately an n-power function of the supply voltage, where n is the number of stages. Care shall be taken to control and measure the total voltage accurately and maintain within close tolerances the ratios of the values of the resistors in the voltage divider chain.

3.3 Uniformity of Anode Luminous Sensitivity Over the Active Cathode Area

3.3.1 In any phototube, the anode luminous sensitivity over the active cathode area (measured according to Fig. 2), will not be absolutely uniform because of non-uniformity of the intrinsic cathode sensitivity (measured according to Fig. 1), and other effects, such as variation in electron collection efficiency over the cathode area.

3.3.2 The uniformity may be expressed as percentage variation from the median sensitivity, or as the minimum-to-maximum ratio, or by a map of the cathode showing equal-sensitivity contour lines.

3.3.3 The uniformity of sensitivity may be measured by systematically scanning the cathode area with a small spot of light of constant flux, of known spectral composition and stated dimensions while measuring the current from the tube (operated under stated conditions). The method of scanning may be manual, electromechanical or electronic.

3.3.4 For rapid qualitative inspection, a two-dimensional flying-spot scanning system may be utilized, and the electrical output of the tube presented on a cathode-ray tube. Variation in sensitivity over scanned cathode area may be observed as a shading in the presented picture.

3.3.5 For taking quantitative data with this system, the output from a single-line sweep across the photocathode may be presented on a calibrated oscilloscope.

3.3.6 The non-uniformity of anode luminous sensitivity also depends on non-uniformities of absolute, as well as of relative spectral sensitivity.

3.4 Spectral Sensitivity Characteristic

3.4.1 The sensitivity of the photocathode to incident monochromatic light of different wavelengths is measured using apparatus described in **4.5** of IS : 7146 (Part I)-1973*. If the resulting absolute spectral sensitivities are referred to the sensitivity at a certain wavelength, the relative spectral sensitivity is obtained.

3.4.2 These values may be normalized, with the peak response taken as unity. A typical curve is described in Fig. 1 of IS : 1885 (Part IV/Sec 8)-1973†.

3.4.3 The electrical circuit is the same as that shown in Fig. 1. The photocathode currents involved are frequently so small that the current meter shall be a galvanometer of high sensitivity or a meter coupled to an amplifier.

3.4.4 If the light is not chopped, a dc amplifier shall be used, but chopped light and an ac amplifier are generally preferable.

3.5 Cathode Spectral Sensitivity — This may be measured directly (usually at the wavelength for which the sensitivity is the greatest) using the circuit shown in Fig. 1, and replacing the calibrated lamp with a source of monochromatic radiation. The cathode spectral sensitivity is the ratio between the photocurrent and the value of the incident monochromatic radiant flux.

3.6 Anode Spectral Sensitivity — This may be measured directly (usually at the wavelength for which the sensitivity is the greatest) using the circuit

*Methods of measurements on photosensitive devices: Part I Basic consideration.

†Electrotechnical vocabulary: Part IV Electron tubes, Section 8 Photosensitive devices.

shown in Fig. 2, and replacing the calibrated lamp with a source of monochromatic radiation. The anode spectral sensitivity is the ratio between the anode current and the value of the incident monochromatic radiant flux.

3.7 Current Amplification

3.7.1 The current amplification G is the ratio between the anode signal current I_a and the cathode signal current I_k at stated electrode voltages:

$$G \rightarrow = \frac{I_a}{I_k}$$

For large values it is difficult to make this measurement in one step because the cathode signal current has to be made extremely low, in order that the anode current will not exceed the stated maximum. The amplification can be measured in steps by one of the three following methods, based on the following assumptions:

a) The photocathode, dynode and anode currents are directly proportional to the incident luminous flux; and

b) The amplification is constant, whatever the value of the luminous flux and its wavelength may be.

3.7.2 The incident radiation and a reduced overall voltage are chosen so that the cathode current I_{k_1} is just large enough to be measured. The anode current I_{a_1} is measured and is of course higher than the cathode current by some factor (for example 1 000). The radiation is then decreased by a suitable factor and the resulting lower value of anode current I_{a_2} is noted.

3.7.2.1 The overall voltage is now increased to its normal value, whilst keeping the incident flux constant, and the resulting value of anode current I_{a_3} is again noted. The overall amplification G is the ratio between the first value of anode current I_{a_1} and the second value of anode current I_{a_2} multiplied by the ratio between the third value of anode current I_{a_3} and the first value of cathode current I_{k_1}, that is:

$$G = \frac{I_{a_1}}{I_{a_2}} \times \frac{I_{a_3}}{I_{k_1}}$$

3.7.2.2 If necessary, measurement may be carried out in several steps.

3.7.2.3 *Precaution* — Cathode current and anode current shall be proportional to each other, otherwise the measurement is not valid.

NOTE — Leakage currents shall not be included.

3.8 Anode Sensitivity Characteristics

3.8.1 *Anode to Last Dynode Current Characteristic* — The anode current is measured as a function of the voltage between the anode and the last dynode while the other voltages on the tube are kept at a stated value.

3.8.1.1 The characteristic is basically similar to that of a diode vacuum phototube, however, as a result of the current amplification in the preceding stages, the anode current is frequently so large that, at conventional voltages, space charge may cause a non-linear relationship between flux and anode current. Therefore, a family of curves of current versus voltage at various constant flux levels shall be obtained.

3.8.2 *Overall Amplification and Sensitivity Characteristics* — These characteristics are measured with a stated ratio of electrode voltages by applying a variable overall voltage to the divider supplying the voltages of the individual electrodes. Current amplification and anode (luminous or radiant) sensitivity usually follow an *n*-power function of voltage (*see* **3.2.10**). It is convenient, therefore, to plot the variation of the logarithm of these quantities versus overall applied voltage.

3.9 Dynamic Characteristics

3.9.1 *General Considerations Applicable to Equipment and Methods of Measurement* — Depending on the applications for which photomultipliers are designed, different dynamic characteristics need to be measured. These are:

a) response pulse duration (and/or rise time of the output current pulse),

b) transit time,

c) variation in transit time with position of illumination, and

d) transit time jitter.

3.9.1.1 The light signal may conveniently be represented by either a delta function or a step function, having respectively a duration or a rise time negligible compared with the characteristic to be measured. If a step function or another input function is used, the response shall be corrected to that corresponding to a delta function; for example if a step function is used, the output pulse is differentiated and the resulting pulse is the equivalent output pulse for a delta input pulse.

3.9.1.2 Space charge saturation or other sources of non-linearity shall be avoided.

3.9.1.3 The spectral, spatial and temporal distributions of the light incident on the photocathode shall be stated.

The usual circuitry shall provide adequate decoupling of dynodes.

The total working voltage and the voltage distribution shall be stated.

Suitable light-pulse generators are:

a) a mechanical light pulser,

b) a device giving a spark discharge in hydrogen,

c) a mercury switch capsule giving a spark discharge*,
d) a Kerr cell and a light source, and
e) semiconductor light sources.

The detector necessary to determine the shape and instant of occurrence of the output pulses is usually an oscilloscope which shall have sufficient bandwidth and sensitivity to prevent time and amplitude distortion of the output pulse. In several measurements, however, special viewing devices and time coincidence circuits are necessary.

3.9.2 *Response Pulse Duration* — When the photocathode receives a delta function light pulse of sufficiently large amplitude to give a statistically stable output current pulse, the time interval between the half amplitude points of this output current pulse, as seen on an oscilloscope, depends on:

a) the phenomenon of charging the anode capacitance by the group of electrons, then of discharging it through the load resistor; and
b) variations in transit time with position of illumination, and transit time jitter.

3.9.2.1 It should be noted that, even if the input were an ideal delta function, the output pulse would have a non-negligible duration.

3.9.2.2 Because transit time depends on the position of the illuminated area of the photocathode, the response pulse duration is maximum when the entire photocathode is illuminated; however, it may be desired to make the measurement with the illumination on a circular area of stated size centred on the photocathode.

3.9.2.3 The rise time of the output current pulse resulting from a delta function light input is sometimes an important characteristic and may be obtained more accurately than the response pulse duration with simple measurements; this is because the decay time of the output pulse depends very significantly on the comparatively long decay characteristic of the light source, as well as on the decay characteristic of the tube. As no source can supply perfect delta function light pulses, in practice the light pulse generator shall be such that the time duration t_1 between the half-amplitude points of the light signal is small with respect to the response pulse duration t to be measured (in general $t_1 \leqslant 1$ ns); the light intensity shall be sufficient to allow the exact shape of the light signal to be distinguished by means of a fast vacuum-photocell having plane parallel electrodes.

As the pulse shapes do not differ very much from Gaussian functions, the response pulse duration t is obtained from the following, t_2 being the time

*CAUTION — The glass capsule of a mercury switch is filled with gas at high pressure and should be handled with great care to avoid injury from explosion. However, this is a very useful light source because it provides a pulse having a short rise time and an accurately synchronized electrical pulse.

duration between the half-amplitude points of the output current pulse as seen on the oscilloscope:

$$t = \sqrt{t_2^2 - t_1^2}$$

3.9.3 *Transit Time* — A suitable arrangement for measuring transit time is shown in Fig. 3. The length of the delay cable is chosen so that the time difference, between the electrical marker pulse from the light pulser and a stated point on the output current pulse, can be determined on the oscilloscope. If the light input and the marker pulse are both delta functions, the time delay is measured from the peak of the marker pulse to the peak of output pulse. If the light input is a step function, the equivalent time delay for a delta input function may be obtained by measuring from the peak of the marker pulse to the point of maximum slope of the output pulse.

The transit time of the tube t_t is:

$$t_t = t_o + t_d - (t_L + t_a)$$

where

t_o = time interval between the marker pulse and the output pulse,

t_d = electrical transit time of the delay cable,

t_L = time required for the light pulse to travel from the light source to the photomultiplier, and

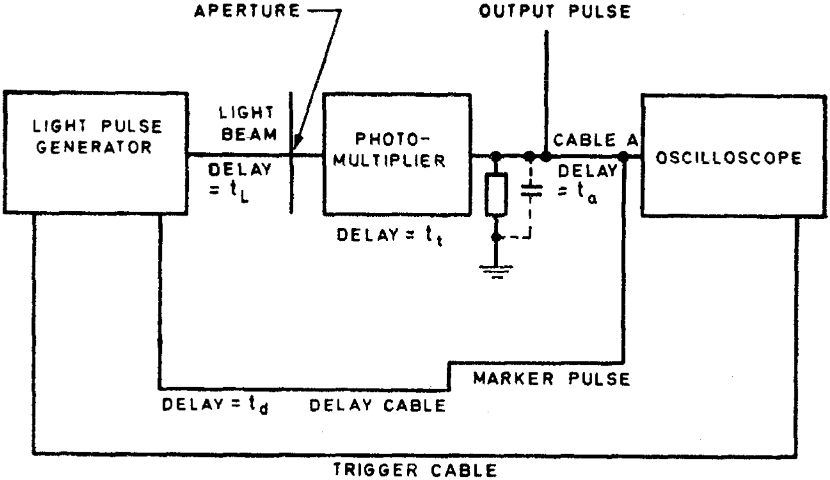
t_a = electrical transit time of cable *A*.

3.9.3.1 Since transit time varies inversely as the square root of the applied voltage, and is also a function of the position of the illuminated cathode area, the operating voltages and manner of applying illumination shall be stated.

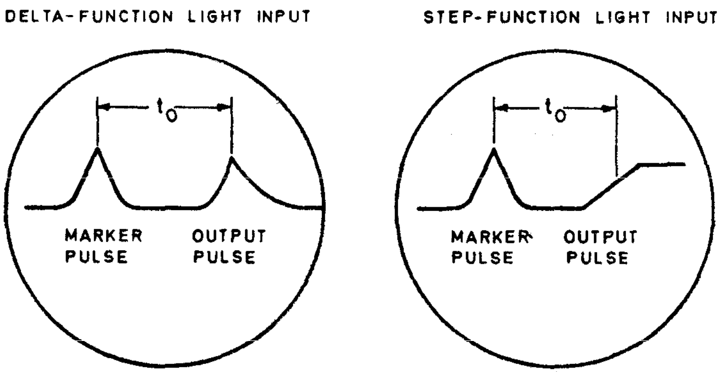
3.9.4 *Variation in Transit Time with Position of Illumination* — Variation in transit time from different positions of the illuminated area of the photocathode may be one contributing cause to a large pulse response duration, and is, consequently, a useful characteristic for predicting pulse response duration. In making this measurement, the adjustable aperture (*see* Fig. 3) shall be closed to the point where the diameter of the illuminated spot is about 5 percent of the diameter of the photocathode. When this small area of illumination is shifted over the photocathode, a variation in transit time is observed.

3.9.4.1 The variation in transit time from that at the reference position, which is usually the centre of the photocathode, is measured as a function of the both radius and azimuth. All electrode voltages shall be stated.

3.9.5 *Transit Time Jitter* — The measurement of transit time jitter may be made by means of the equipment of Fig. 4, which gives a very simplified block diagram. The delta function light pulses, provided by the source



3A Block Diagram of Equipment



3B Oscilloscope Traces

Fig. 3 System for Measuring Transit Time and Related Characteristics

described in **3.9.1** and **3.9.2**, and under the same conditions, shall be so attenuated, before reaching the photocathode, that, for each light pulse, the photocathode emits no more than one single electron.

3.9.5.1 Through a time-to-amplitude convertor, the time intervals between a stated point to the anode pulse corresponding to that single electron

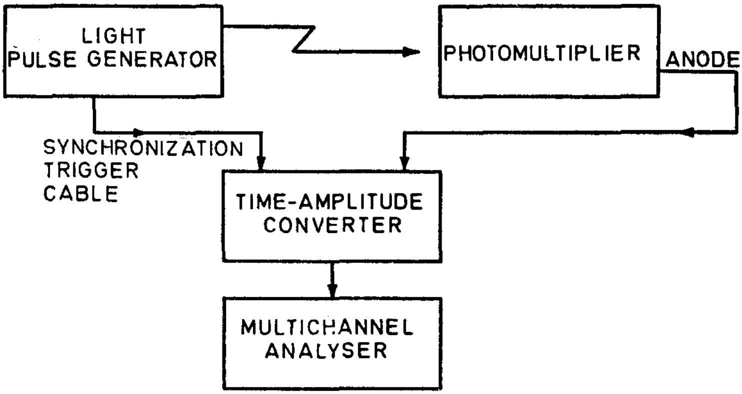


FIG. 4 SIMPLIFIED BLOCK DIAGRAM OF THE EQUIPMENT TO MEASURE TRANSIT TIME JITTER

and a signal synchronous with the light signal, are recorded on a multichannel analyser. Provided the recording time is sufficiently long that statistical errors can be neglected, the shape of the pulse obtained on the screen of the analyser is that of the light pulse modified by the errors introduced by transit time jitter.

As the pulse shapes do not differ very much from Gaussian functions, the transit time jitter may be represented by:

$$t = \sqrt{t_3{}^2 - t_1{}^2}$$

where

t = duration between its half-amplitude points,

t_3 = duration between its half-amplitude points, and

t_1 = duration between its half-amplitude points.

3.10 Dark Current — The following measurement conditions are applicable to all dark current measurements, unless otherwise stated:

a) During measurements, the tube shall be placed in a lightproof enslosure, as described in **4** of IS : 7146 (Part I)-1973*. For some tubes, exposure to light within an hour or more immediately preceding the measurement may result in a higher dark current than for unexposed tubes.

*Methods of measurements on photosensitive devices: Part I Basic considerations.

b) The electronic circuitry is the same as that shown in Fig. 1 or 2.

c) Electrode voltages and ambient temperature shall be carefully controlled at stated values because they affect the dark current of photomultipliers.

d) Socket leakage shall be subtracted from electrode dark current to obtain the net dark current.

This leakage varies with changes in ambient temperature, humidity and voltage.

3.10.1 *Anode Dark Current* — Anode dark current is measured at stated electrode voltages, or at electrode voltages required to provide a stated luminous sensitivity.

3.10.1.1 Possible causes of anode dark current are electrical leakage (tube, not socket), thermionic emission, field emission, residual gas ionization and tube fluorescence. At low operating voltages, its major components are normally electrical leakage or thermionic emission or both.

3.10.1.2 Thermionic emission and residual gas ionization can be recognized by their temperature dependence. At high values of applied voltage and the corresponding current amplification, the other dark current components may become an appreciable part of the total dark current.

3.10.2 *Equivalent Anode Dark Current Input* — The equivalent anode dark current input, in lumens, may be determined by measuring the anode dark current and anode luminous sensitivity at stated electrode voltage, or at electrode voltages providing a stated anode luminous sensitivity and making use of the following equation:

$$\text{Equivalent anode dark current input (lumens)} = \frac{\text{Anode dark current (amperes)}}{\text{Anode luminous sensitivity (amperes/lumen)}}$$

The equivalent anode dark current input, in watts (at a particular wavelength), may be obtained in a similar manner using the following equation:

$$\text{Equivalent anode dark current input (watts)} = \frac{\text{Anode dark current (amperes)}}{\text{Anode radiant sensitivity (amperes/watt)}}$$

3.10.3 *Equivalent Anode Dark Current Input Sensitivity Characteristic* — This characteristic can be shown as a curve relating to the values of the equivalent anode dark current input (lumens) to values of anode luminous sensitivity (amperes/lumen) or equivalent anode dark current input (watts, at a specified wavelength) to values of anode radiant sensitivity (amperes/watt, at a specified wavelength).

3.10.4 *Temperature Characteristic of Dark Current* — In cases where it is of interest, a graph of anode dark current or equivalent anode dark current input as a function of equilibrium temperature normally covers the range of – 65°C to the maximum rated tube temperature (usually shall not exceed + 45°C).

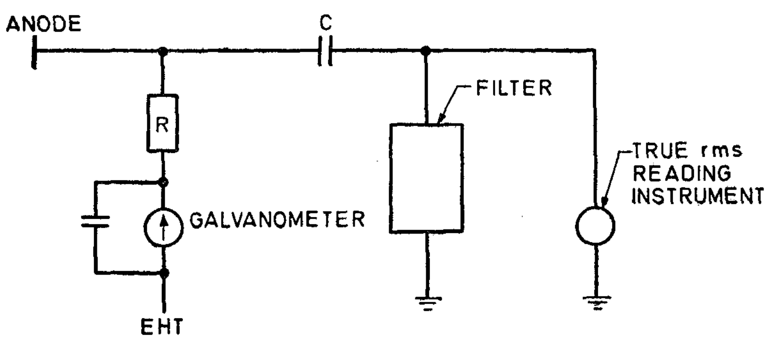
3.10.4.1 With certain cathodes, erratic measurements may result from excessive cathode resistance when the tube is operated at low temperature.

3.10.4.2 This curve depends on the type of tube and, moreover, varies among tubes of the same type.

3.10.5 *Electrode Dark Current in a Photomultiplier* — High values of electrode dark current, other than anode dark current, may produce a serious loading effect, especially when the current in the potential divider is low and, thereby affects the voltage distribution to the electrodes.

3.10.5.1 To measure the dark current of an electrode, the stated voltages shall be applied to all electrodes and the current shall be read on a meter inserted in the stated electrode lead.

3.11 Noise — Signal-to-noise ratios may be measured with the circuit shown in Fig. 5, with a filter having defined equivalent noise bandwidth. A true rms reading instrument is used.



R and *C* are incorporated in the filter.

FIG. 5 CIRCUIT TO MEASURE SIGNAL-TO-NOISE RATIO

3.11.1 Signal-to-noise ratios are measured under specified conditions; electrode voltages, incident flux, illuminated area, ambient temperature, amplifier bandwidth, anode load and stray capacitance shall be stated. A standard lamp shall be used.

3.11.2 *Signal-to-'Noise in the Signal' Ratio* (*SNR*) — The signal-to-'noise in the signal' ratio is dependent on the statistical variation of the electron current leaving the photocathode, on the efficiency of electron collection at the first dynode, on the statistical variation of electron multiplication at the first few dynodes and on the frequency band.

The signal-to-'noise in the signal' ratio is:

$$\text{SNR} = \frac{\text{Signal output current}}{\text{RMS noise in the signal output current}}$$

3.11.3 *Signal-to-Dark Current Noise Ratio* — Under the stated operating conditions, the signal output current is measured by the galvanometer with the light on. With the light off, the rms dark current noise output is measured. The signal-to-dark current noise ratio is:

$$\frac{\text{Signal output current}}{\text{RMS dark current noise output}}$$

3.11.4 *Equivalent Dark Current Noise Input* — The equivalent dark current noise input for unit bandwidth is given by:

$$\frac{F}{\sqrt{B}} \times \frac{n}{S} \ (\text{lm/Hz}^{\frac{1}{2}})$$

where

F = luminous flux in lumens used in measuring the signal to dark current noise ratio,

B = bandwidth of filter in hertz, and

$\frac{S}{n}$ = signal-to-dark current noise ratio.

3.12 Peak Output Current Limitations

3.12.0 The output current of a photomultiplier can be limited by two effects:

a) space charge, and

b) high resistivity of the photocathode.

3.12.0.1 In general, the first effect is likely to occur in the last stages of a photomultiplier where the currents may be relatively high, while the second effect is found only in semitransparent photocathodes.

3.12.0.2 Space-charge saturation in a photomultiplier can be distinguished from saturation caused by a high-resistivity cathode by measuring the output current with increased voltage between some of the early dynodes to increase the current amplification. The output current will be increased if the saturation is caused by cathode resistivity, but it will not be affected if the saturation is due to space charge in one of the last few dynodes.

3.12.0.3 Drift or temperature dependence of the saturation output current indicates high cathode resistivity. The static and dynamic impedance of the supply to the dynodes shall be as low as possible.

3.12.1 *Space-Charge-Limited Output Current* — Space charge may cause a limitation in output current which, above a certain level of illumination, departs from linearity and increases relatively less. In the extreme of complete space-charge saturation, the anode current remains constant with increasing illumination.

3.12.1.1 As the deviation from linearity starts very gradually, an exact value for the permissible peak output current for linear operation can be stated if the permissible deviation from linearity is defined. For most purposes, a deviation of 5 percent is a reasonable value.

3.12.1.2 The output current is measured while the illumination is varied by known amounts; this is best done by the use of calibrated neutral filters, or by changing the distance between the light source and the photocathode and applying the inverse-square law. The measurement may be made by dc methods with steady illuminations, up to values of current at which electrode dissipation exceeds safe values.

3.12.1.3 For higher values of current, pulsed light is used and peak values of incident light flux and output current are measured.

3.12.1.4 A cathode-ray oscilloscope is commonly used as current indicator; it shall be checked that the shape of the output current pulse has not changed, as very often a variation of the rise time can be seen before the peak current changes.

3.12.1.5 A simple method requiring no photometric calibration is to compare on a *X Y* oscilloscope the anode pulses delivered by two photomultipliers excited by a common light source, as indicated in Fig. 6. The photomultiplier that is lighted by the attenuated flux shall be sufficiently fast not to distort the pulses, even at low level. Every departure from linearity in the photomultiplier being measured appears as a deviation from the straight line obtained when the pulses from both photomultipliers are perfectly proportional. The output level at which the deviation from the straight line reaches a given value, for instance 5 percent, defines the limit of linearity.

3.12.1.6 Suitable light sources are pulsed cathode-ray tubes with very short persistance phosphors, gas discharge lamps or incandescent lamps with mechanical shutters.

3.12.2 *Peak Output Current Limited by High Cathode Resistivity* — The limiting cathode current for semitransparent cathodes is determined by the type of cathode used. High cathode resistivity may result in an anode current which increases non-linearity with illumination.

3.12.2.1 The test for linearity is the same as that described in **3.12.1.** If a tube with semitransparent cathode is to be used at low temperature (for example liquid nitrogen), the linearity test shall be carried out at this temperature because the resistivity usually increases with decreasing temperature.

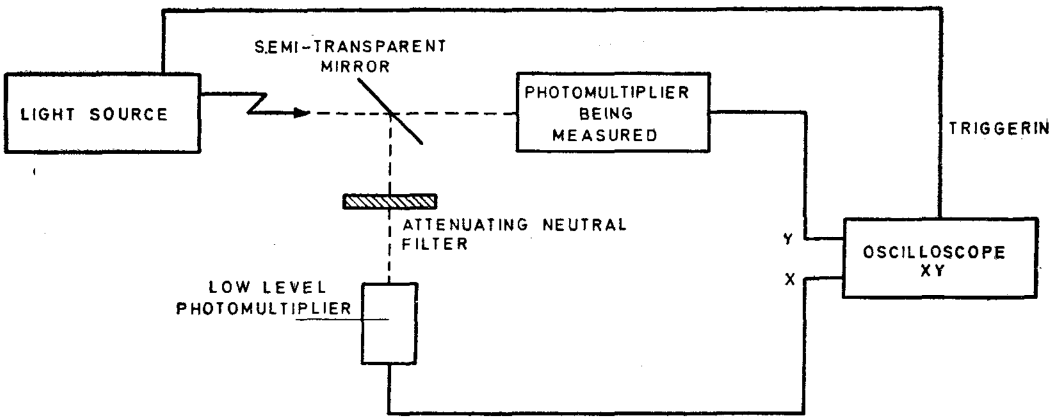


FIG. 6 SYSTEM FOR MEASURING THE LINEARITY OF ANODE CURRENT VERSUS LUMINOUS FLUX

3.13 Precautions

3.13.1 *Fatigue* — Some phototubes under normal operating conditions exhibit a temporary change in sensitivity, termed fatigue. Fatigue may be expressed in terms of percentage change in sensitivity under stated operating conditions including all electrode voltages, total radiant flux, time of exposure to radiation and output current. Sensitivity is measured at the beginning and the end of the radiation period according to one of the methods specified in **3.1**.

3.13.1.1 Frequently a fatigue characteristic is obtained by measuring relative sensitivity as a function of time duration at stated periods from the start of operation.

3.13.2 *Fields* — To some degree, all photomultipliers are sensitive to the presence of magnetic fields.

3.13.2.1 The loss of gain results from the deflection of electrons from their normal path between stages. Tubes for scientillation counting are, generally, quite sensitive to magnetic fields because of the relatively long path from the cathode to the first dynode.

3.13.2.2 If photomultipliers are to be used in the presence of magnetic fields, as is often the case, it is essential to provide magnetic shielding around the tube.

3.13.2.3 High-mu-material shields are generally available commercially. In some experiments, even the earth's magnetic field may be critical, especially if the tube is moved about. It is possible to take advantage of magnetic fields to modulate the output current of the photomultiplier. Under the application of normal fields, no permanent damage results. But it is possible to cause a slight magnetic polarization of some of the internal structure of the tube. If this condition shall occur, the performance of the tube may be somewhat degraded by loss in collection efficiency; however, it is a simple matter to 'degauss' (demagnetize) the tube by placing it in an alternating magnetic field and then gradually withdrawing it. A maximum field of 0·01 T at the centre of a coil operated on a 50 to 60 Hz alternating current is usually sufficient to degauss a tube.

INDIAN STANDARDS

ON

PHOTOSENSITIVE DEVICES

IS:

1885 (Part IV/Sec 8)-1973 Electrotechnical vocabulary: Part IV Electron tubes; Section 8 Photosensitive devices

7146 (Part I)-1973 Methods of measurements on photosensitive devices: Part I Basic considerations

7146 (Part II)-1974 Methods of measurements on photosensitive devices: Part II Phototubes

7146 (Part III)-1974 Methods of measurements on photosensitive devices: Part III Photoconductive cells for use in the visible spectrum

7146 (Part IV)-1974 Methods of measurements on photosensitive devices: Part IV Photomultipliers